

Simulation of CLARREO Ability to Calibrate Solar Reflectance Sensors in Orbit using SCHIAMACHY Data

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CLARREO Workshop, October 2008, Washington, DC

Presentation Outline

- ◆ **CLARREO inter-calibration goal**
- ◆ **High spectral resolution SCIAMACHY data**
- ◆ **Definition of simulation parameters:**
 - **CLARREO sampling**
 - **offset**
 - **gain**
 - **relative spectral response (RSR)**
 - **time, space and angle matching noise**
- ◆ **Simulation results:**
 - **broadband instrument (CERES)**
 - **narrowband instrument (MODIS)**
- ◆ **Summary**
- ◆ **Future work**

CLARREO Inter-Calibration Goal

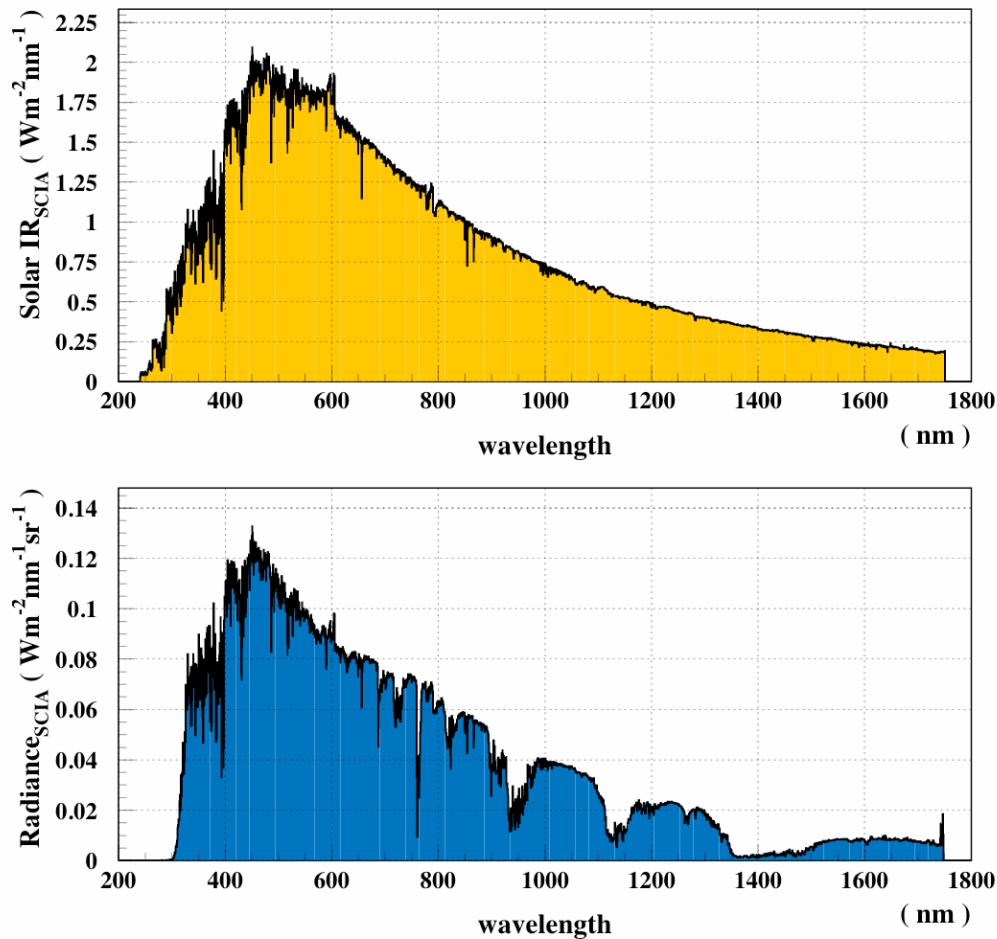
- ◆ **To be able to detect the anthropogenic radiative forcing of $\sim 0.6 \text{ Wm}^{-2} \text{ decade}^{-1}$ (*IPCC Forth Assessment Report, 2007*)
50% change = $0.3 \text{ Wm}^{-2} \text{decade}^{-1}$ globally.**
- ◆ **Relative to 50 Wm^{-2} (global average SW cloud radiative forcing) = 0.6%**
- ◆ **Reducing uncertainty to 25% would require stability of $0.3\% \text{ decade}^{-1}$ for SW broadband (*Loeb et al., 2007*)**
- ◆ **CLARREO Goal: At least 0.2% (2σ) relative accuracy for SW broadband**

SCIAMACHY Data & Scene ID

- ◆ ENVISAT SSP 10 am orbit, 800 km altitude.
- ◆ Level-1B spectral radiance data product, latest available calibration, January and July months for 2003 – 2007 time period.
- ◆ Footprint 30 km x 240 km (T_{int} = 1 s), swath 950 km in 5 integrations.
- ◆ Global coverage in 3-4 days.
- ◆ Spectral range from 240 to 1750 nm wavelength is used.
- ◆ MODIS based Cloud and aerosol parameters from CERES/Terra SSF matched to SCIAMACHY footprints.

Channel	Spectral range (nm)	Spectral Resolution (nm)	Spectral Stability (nm)	Reflectance Errors (%)
1	240 - 314	0.24	0.003	3
2	309 - 404	0.26	0.003	2
3	392 - 605	0.44	0.004	3
4	598 - 790	0.48	0.005	2
5	776 - 1056	0.54	0.005	6
6	991 - 1750	1.48	0.015	4
7	1940 - 2040	0.22	0.003	Problems
8	2260 - 2384	0.26	0.003	Problems

Simulation Approach: use advantages of existing spectral measurements



Plots:

SCIAMACHY measured solar irradiance (daily) and reflected radiance spectra for 2006.07.01

Advantages: SCIAMACHY data allow to simulate natural ensemble of scene types in CLARREO sampling and provide spectra with known radiometric accuracy.

Definition of simulation Parameters

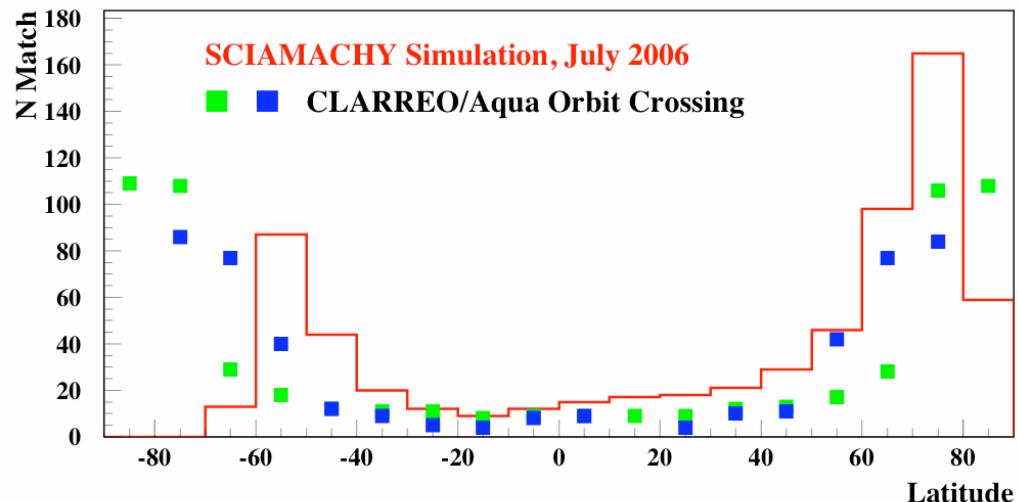
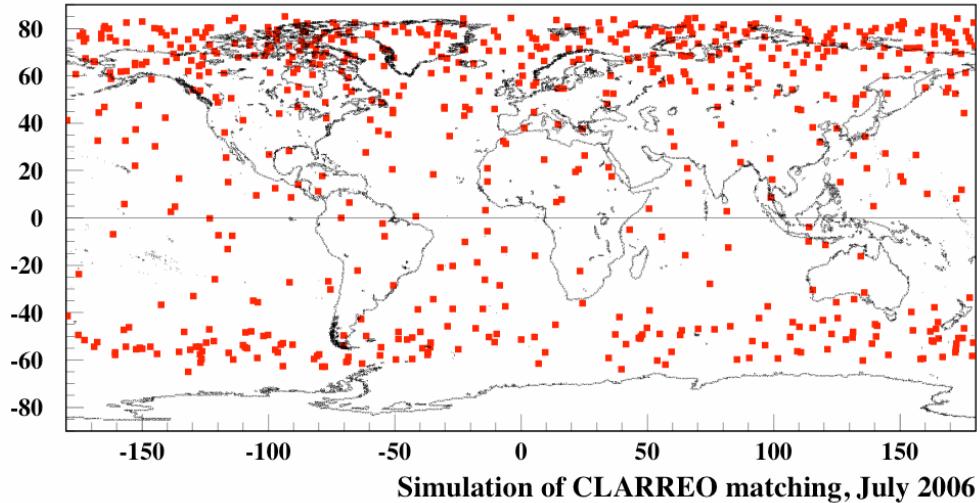
- ◆ **Offset** – constant term of difference between sensor and CLARREO radiance, independent on wavelength, radiance units.
- ◆ **Gain** – linear term of difference, relative to CLARREO gain which is unity.
- ◆ **Nominal RSR** – sensor RSR as it is known.
- ◆ **Simulated RSR** – sensor RSR with degradation for broadband and CW shift for narrowband.
- ◆ **Noise** – combined random noise from time, space and angles mismatching, Gaussian distribution.
- ◆ **Sampling** – simulated CLARREO sampling for nadir-only and pointing capability matching.

Definition of simulated Signals

- ◆ **CLARREO signal:** SCIAMACHY data integrated over nominal RSR (CERES, MODIS), gain = 1.0, offset = 0.0 Wm⁻²sr⁻¹.
- ◆ **Instrument (CERES, MODIS) signals:**
 - 1) SCIA data integrated over nominal RSR (good), gain and offset differences with CLARREO.
 - 2) SCIAMACHY data integrated over simulated RSR (degradation & shifts), NO gain or offset differences with CLARREO.
 - 3) SCIAMACHY data integrated over simulated RSR (degradation & shifts), gain and offset differences with CLARREO.

CLARREO Sampling

CLARREO nadir-only matching



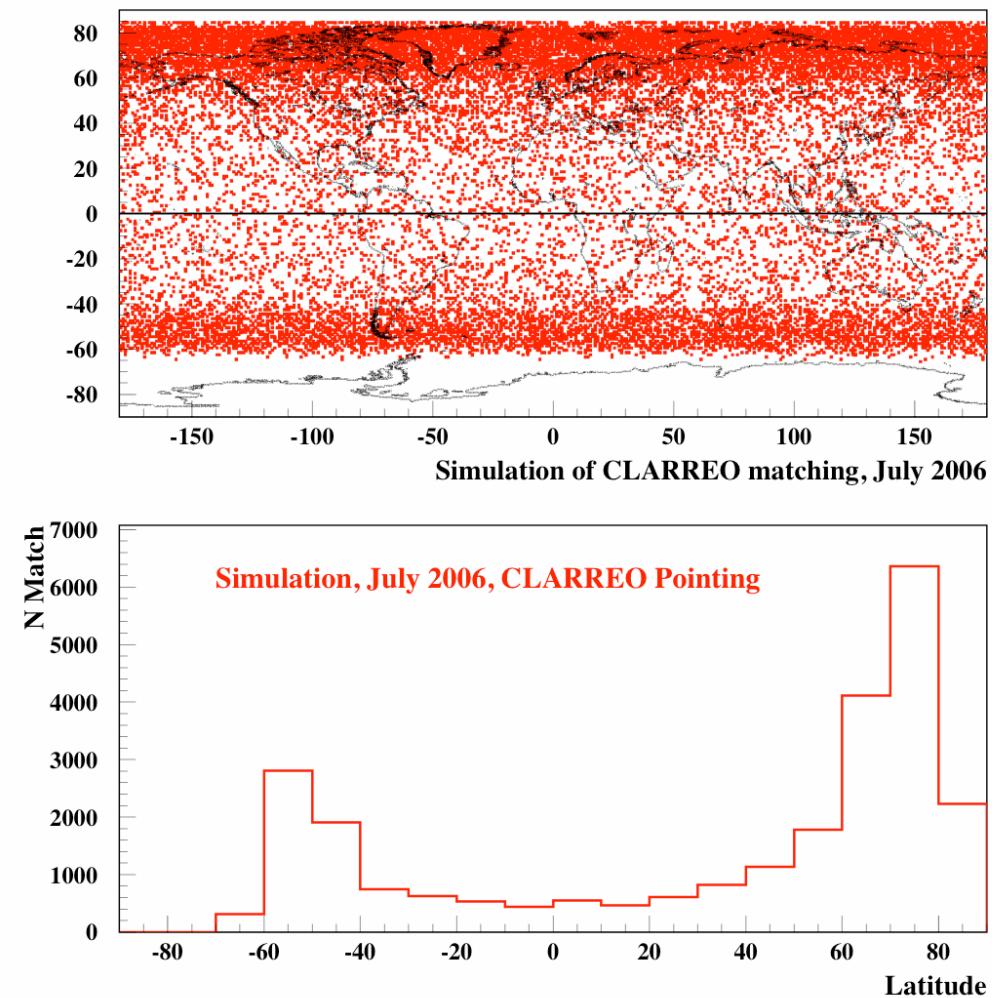
- * SCIAMACHY data of 2006.01 and 2006.07 is used to simulate CLARREO seasonal matching.

- * Footprints selected randomly, probability weighted with sigmoid function. Number of matches = **665 FOV**.

- * CLARREO/Aqua orbit crossing simulation by Doelling / MacDonnell.

CLARREO Sampling

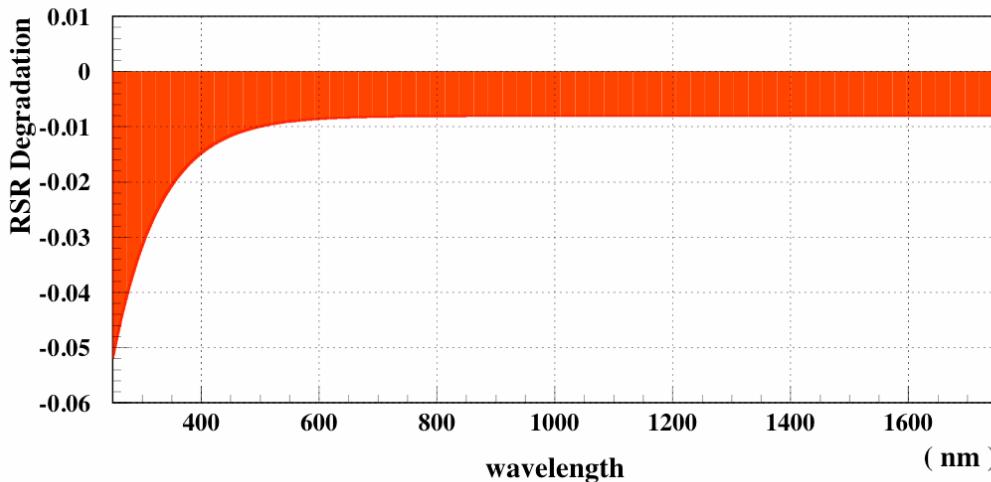
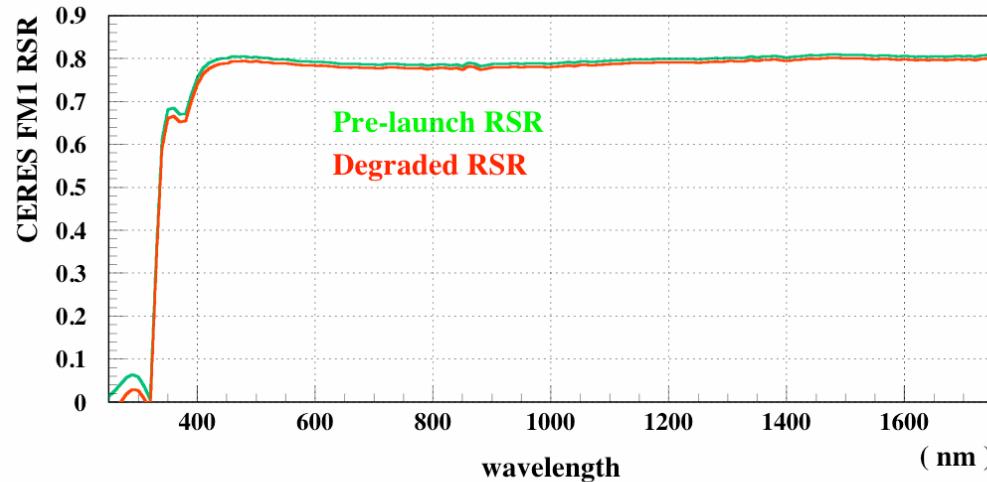
CLARREO matching with pointing ability



- * SCIAMACHY data of 2006.07 is used to Simulate CLARREO Seasonal matching.
 - * Footprints selected randomly, probability weighted with sigmoid function.
 - * Sampling increase: 40 cross-track angle space/time matches per orbit crossing
- N match = **25,435 FOV**

CERES RSR Degradation

Spectral Range used: 240 nm – 1750 nm



CERES RSR Degradation:

$$A + B \exp(-C\lambda)$$

$$A = -0.008$$

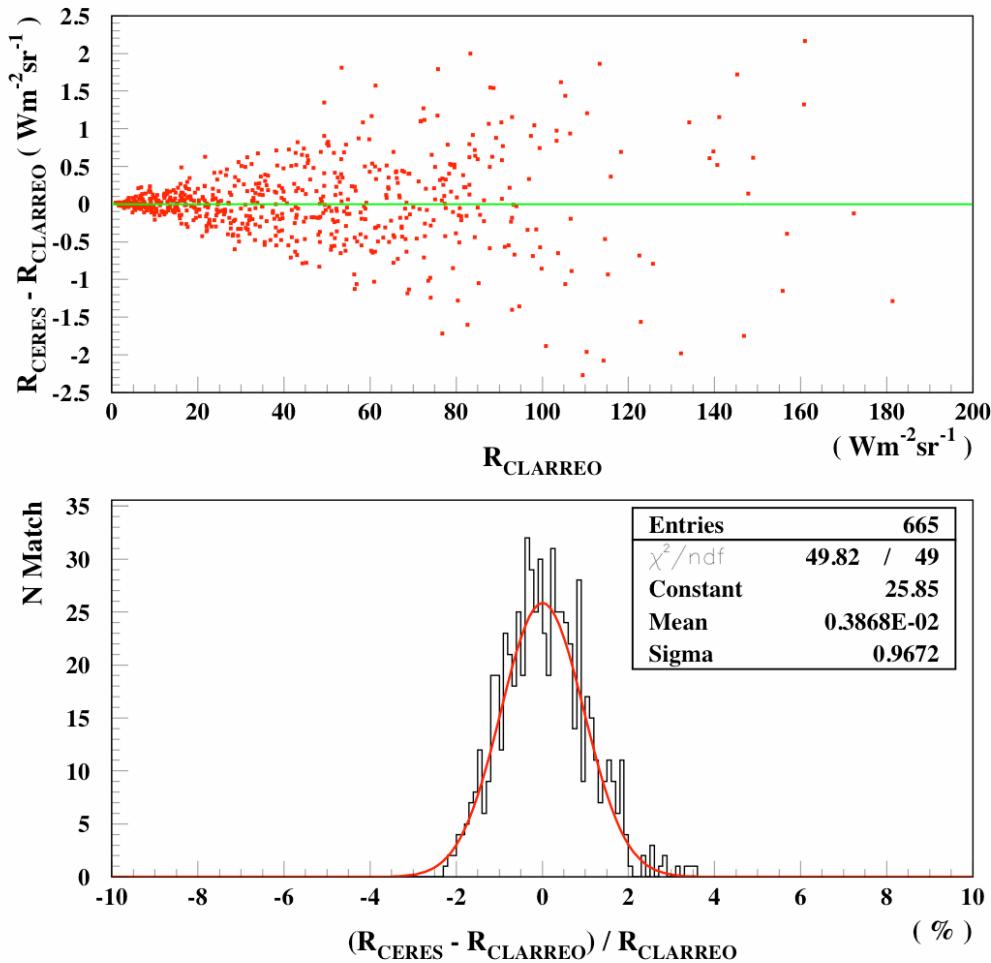
$$B = -1.0$$

$$C = 0.0125$$

Shape: experience from LDEF,
GOME, MODIS.

Magnitude: level of CERES
contamination seen in RAP
scan mode.

Matching Noise: Random Gaussian $\sigma = 1\%$



Matching noise at 1%:

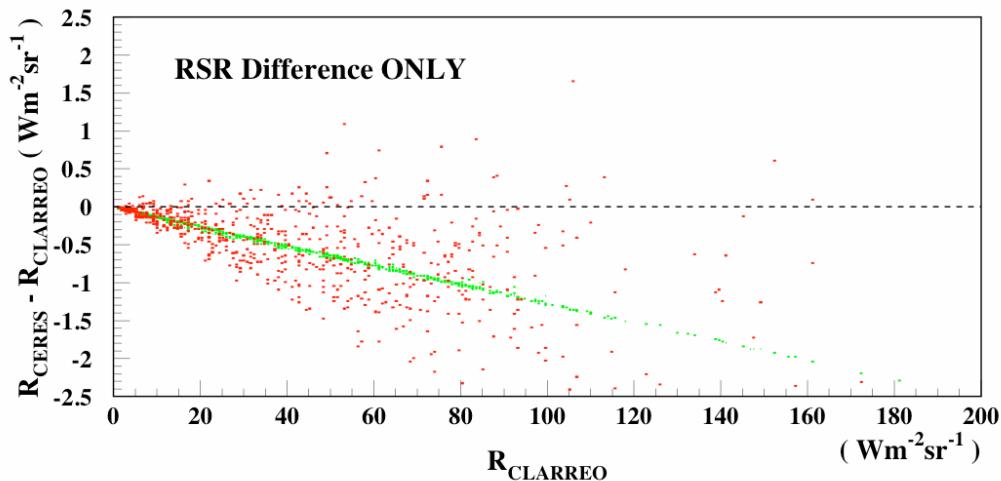
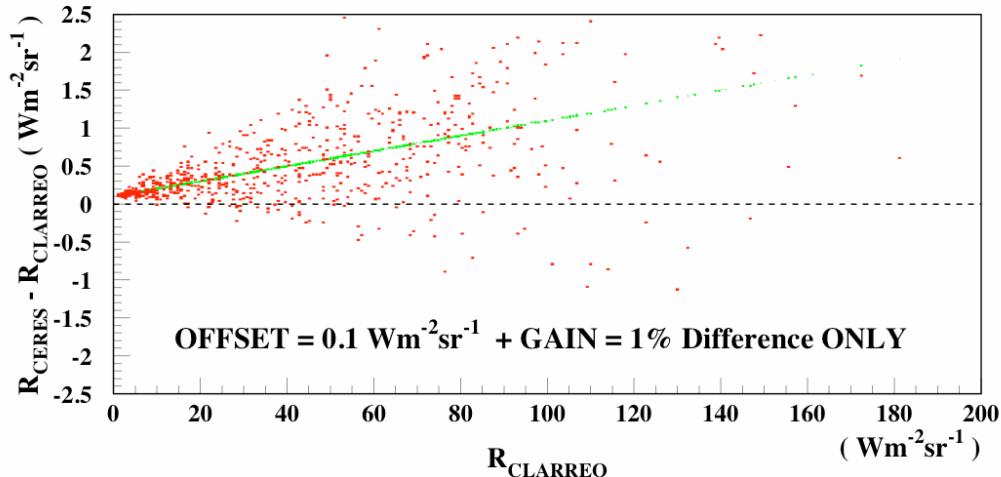
- 1° angle match;
- 100 km FOV match;
- 5 min time match;

Wielicki et al., IGARSS 2008

- *CERES/MODIS matching.*

CLARREO/CERES Calibration

Offset = 0.1 Wm⁻²sr⁻¹, Gain = 1%, Noise σ = 1%



OFFSET + GAIN ONLY :

OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
0.09 ± 0.07	1.10 ± 0.13

* Offset $2\sigma \sim 0.2\%$

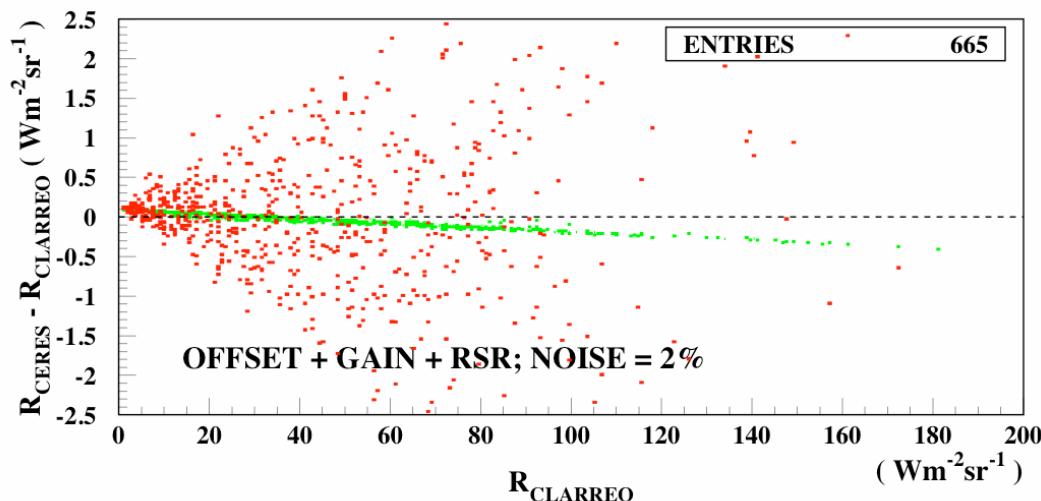
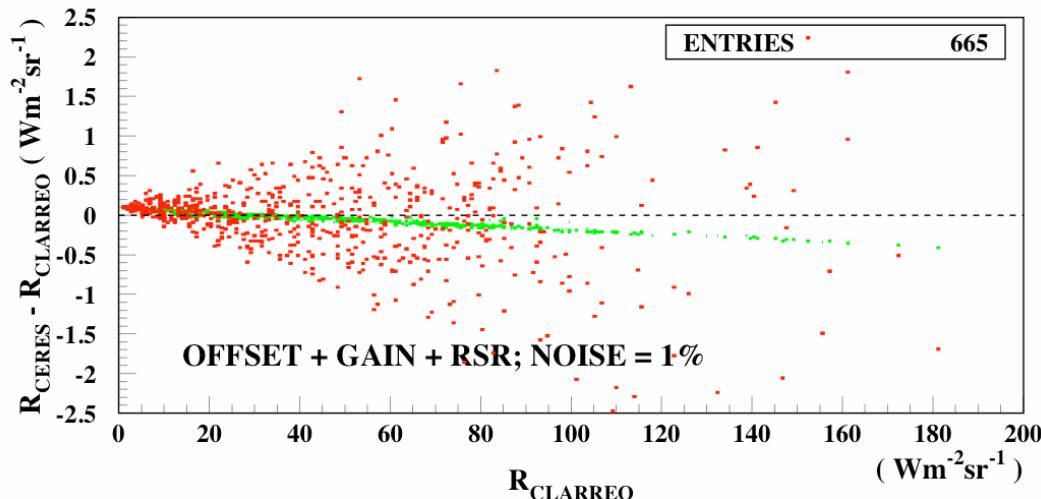
RSR ONLY :

OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
-0.02 ± 0.07	-1.20 ± 0.12

* Format: PAR \pm 95%CL (2 σ)

CLARREO/CERES Calibration

together: Offset=0.1 Wm⁻²sr⁻¹, Gain=1% & RSR



OFFSET + GAIN + RSR :

Noise (%)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
0.0	0.08 ± 0.003	-0.27 ± 0.01
1.0	0.08 ± 0.07	-0.20 ± 0.13
2.0	0.07 ± 0.14	-0.15 ± 0.25

- * Offset $2\sigma \sim 0.4\%$ (at 2% noise)
- * 2% Matching noise does not meet accuracy requirement !
- * Format: PAR \pm 95%CL (2 σ)

CLARREO/CERES Calibration

**Offset = $0.1 \text{ Wm}^{-2}\text{sr}^{-1}$, Gain = 1%, Noise $\sigma = 1\%$,
sampling with CLARREO pointing ability,
N match = 25,435 FOV**

OFFSET + GAIN ONLY :

OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
0.11 ± 0.02	0.99 ± 0.04

* Offset $2\sigma \sim 0.06\%$

OFFSET + GAIN + RSR :

Sample (FOV)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
665	0.08 ± 0.07	-0.20 ± 0.13
25,435	0.09 ± 0.02	-0.29 ± 0.04

RSR ONLY :

OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
-0.01 ± 0.02	-1.27 ± 0.04

* Noise reduction by averaging
in $1.0 \text{ Wm}^{-2}\text{sr}^{-1}$ bins, N > 100 FOV

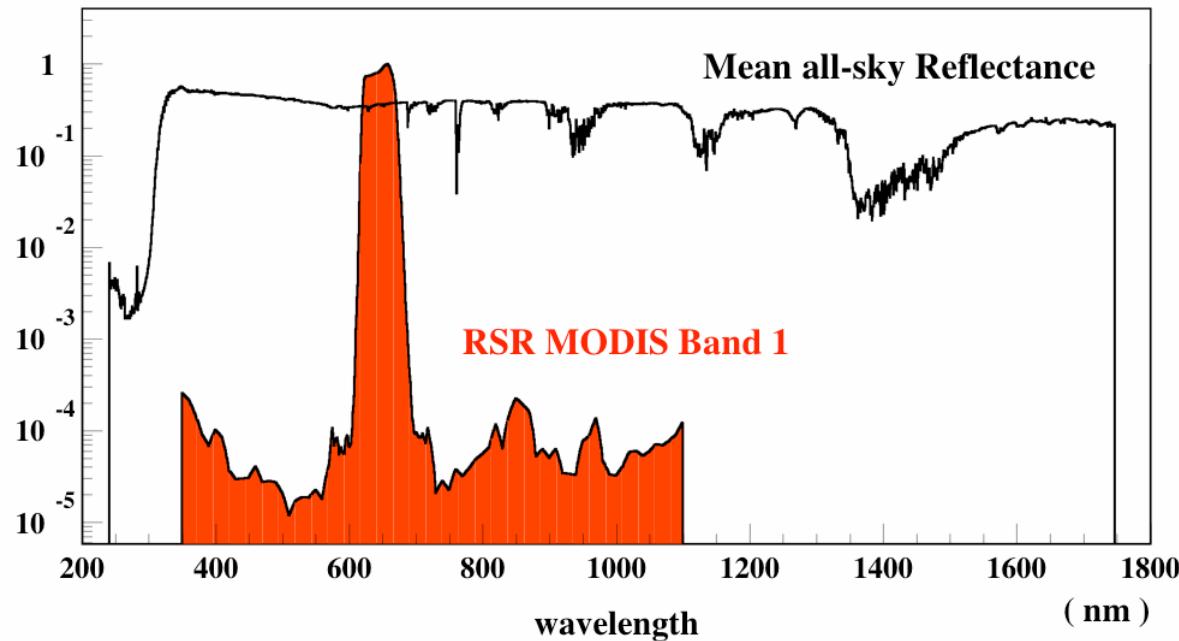
* Format: PAR \pm 95%CL (2 σ)

Summary for CLARREO / CERES Inter-Calibration

- ◆ Uncertainty of inter-calibration is dominated by contribution from matching noise. 2% matching noise does not meet accuracy requirement.
- ◆ To separate effects from OFFSET/GAIN and the RSR degradation the clear-sky scenes should be studied: CERES RSR degradation produces additional offset and noise for clear sky ocean footprints while DDC/marine stratus footprints are not sensitive.
- ◆ Improved sampling (pointing ability) reduces uncertainty (2σ) of OFFSET to $0.02 \text{ Wm}^{-2}\text{sr}^{-1}$ (0.06%) and of GAIN to 0.035%.

CLARREO/MODIS Calibration

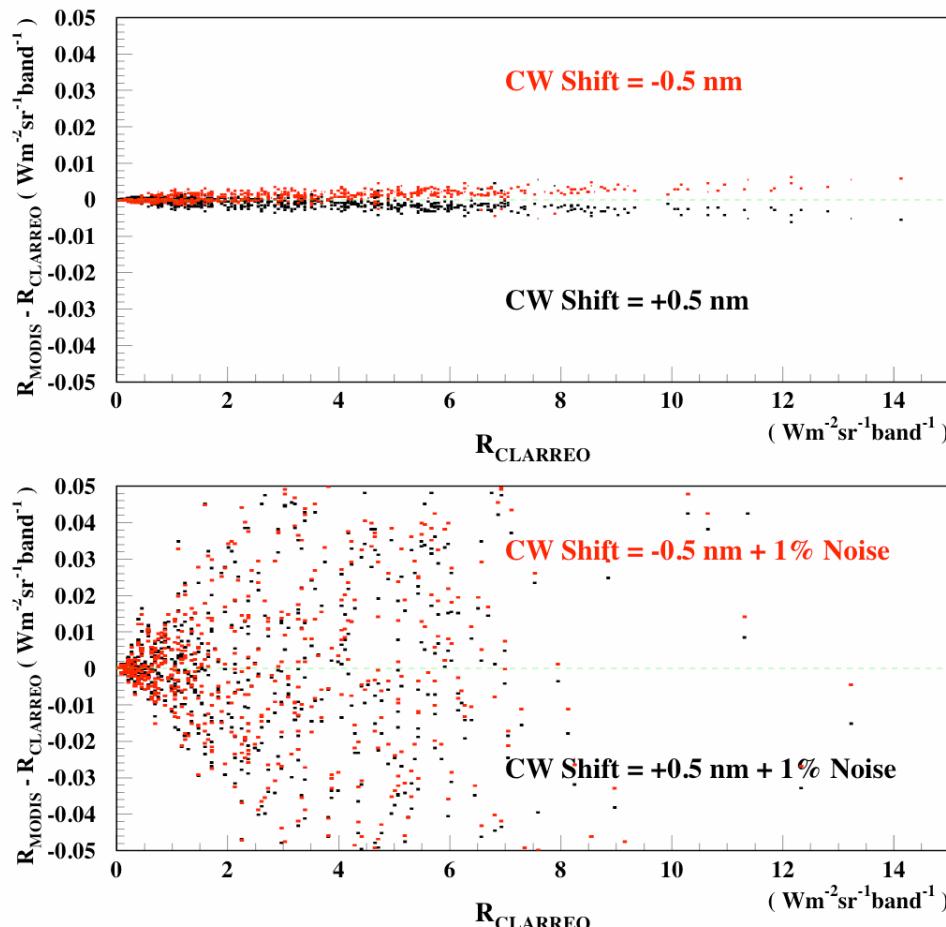
MODIS Band 1 RSR, 620 – 670 nm



- ◆ Reported MODIS RSR central wavelength shifts are within 0.3 nm for MODIS/Terra and 0.6 nm for MODIS/Aqua (*Xiong et al., 2006*)
- ◆ Simulation with SCIAMACHY data is not sensitive to central wavelength shifts below 0.5 nm (resolution).

CLARREO/MODIS Calibration

MODIS Band 1: 620 – 670 nm, 0.5 nm CW Shifts, Nadir-only Sampling, 1% Matching Noise



CW SHIFT ONLY :

Shift (nm)	OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
+0.5	$0.8\text{e-}04 \pm 1.3\text{e-}04$	$-0.03 \pm 3.1\text{e-}05$
-0.5	$-0.7\text{e-}04 \pm 1.3\text{e-}04$	$0.03 \pm 3.1\text{e-}05$

CW SHIFT + NOISE = 1%

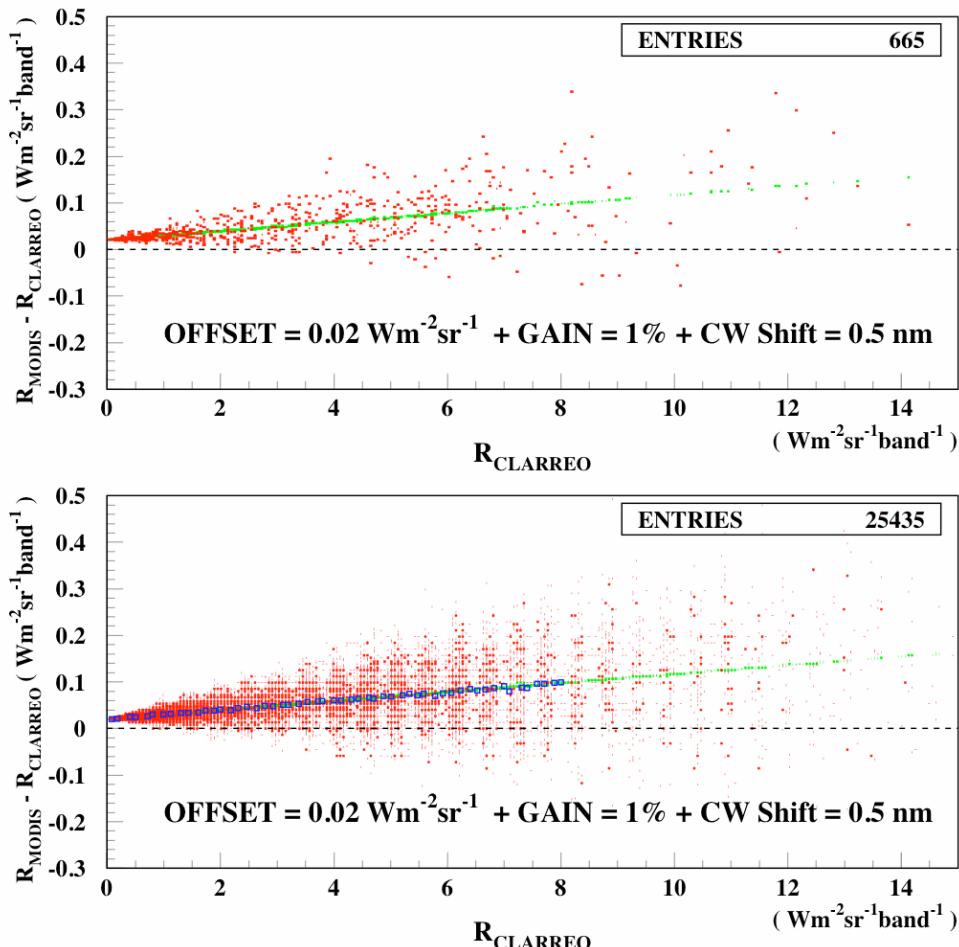
Shift (nm)	OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
+0.5	$-0.2\text{e-}03 \pm 5.0\text{e-}03$	0.03 ± 0.12
-0.5	$-0.3\text{e-}03 \pm 5.0\text{e-}03$	0.09 ± 0.12

* Format: PAR \pm 95%CL (2 σ)

CLARREO/MODIS Calibration

MODIS Band 1: 620 – 670 nm,

0.5 nm CW Shift, Gain 1% , Offset 0.02 Wm⁻²sr⁻¹band⁻¹, 1% Noise



CLARREO Nadir = 665 FOV

OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
0.0198 ± 0.0051	1.03 ± 0.12

* Offset $2\sigma \sim 0.25\%$

* Noise reduction by averaging in $0.15 \text{ Wm}^{-2}\text{sr}^{-1}\text{band}^{-1}$ bins, $N > 100$ FOV.

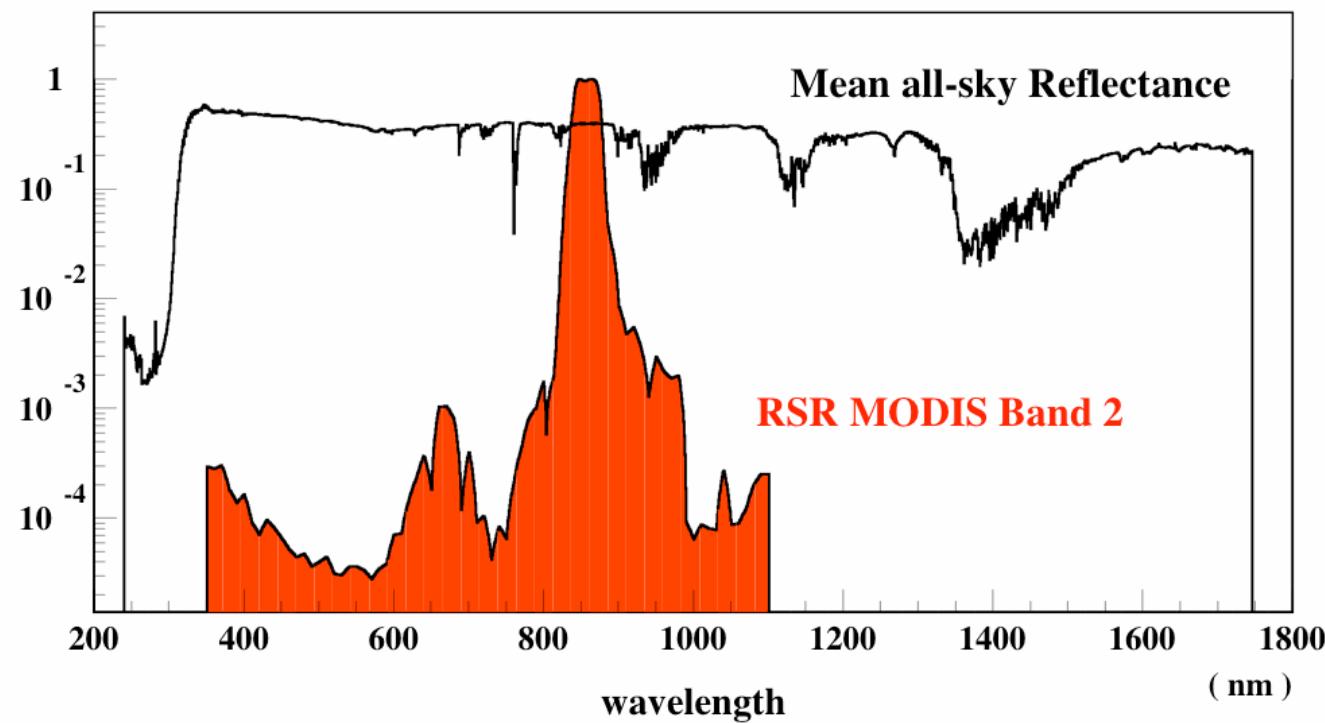
CLARREO Pointing = 25,435 FOV

OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
0.021 ± 0.001	0.960 ± 0.024

* Offset $2\sigma \sim 0.05\%$

CLARREO/MODIS Calibration

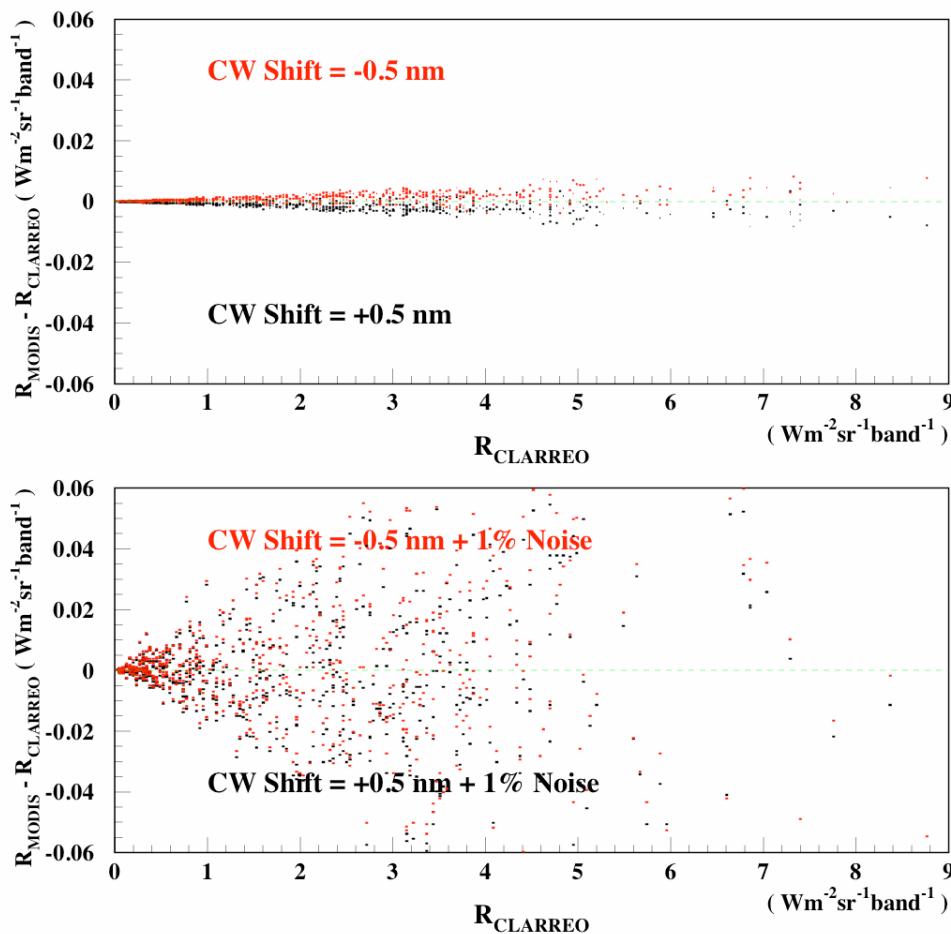
MODIS Band 2 RSR, 841 – 876 nm



- ◆ Reported MODIS RSR central wavelength shifts are within 0.2 nm for MODIS/Terra (*Xiong et al., 2006*)

CLARREO/MODIS Calibration

MODIS Band 2: 841 – 876 nm, 0.5 nm CW Shifts, Nadir-only Sampling, 1% Matching Noise



CW SHIFT ONLY :

Shift (nm)	OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
+0.5	-1.8e-04 ± 1.6e-04	-0.05 ± 6.0e-05
-0.5	1.8e-04 ± 1.7e-04	0.043 ± 6.2e-05

CW SHIFT + 1% NOISE :

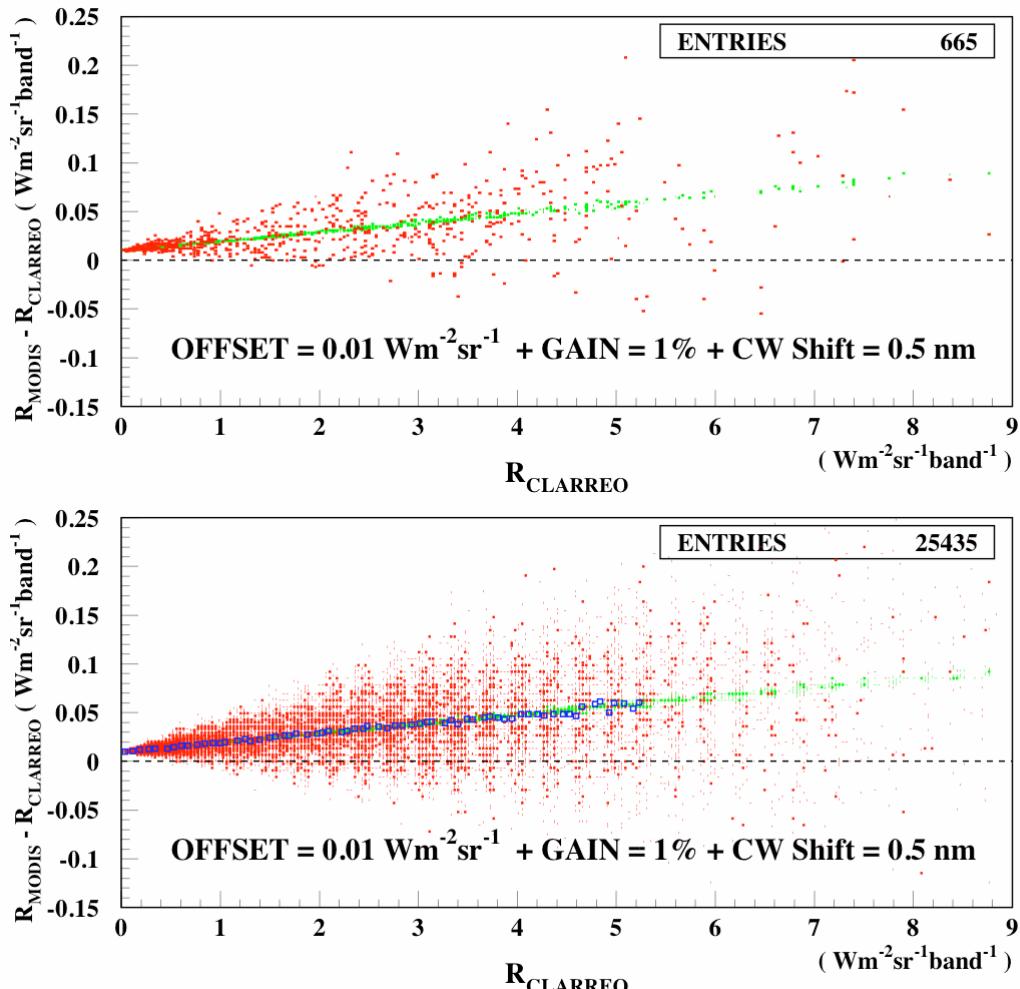
Shift (nm)	OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
+0.5	-0.06e-03 ± 3.3e-03	-0.02 ± 0.12
-0.5	0.3e-03 ± 3.3e-03	0.07 ± 0.12

* Format: PAR ± 95%CL (2 σ)

CLARREO/MODIS Calibration

MODIS Band 2: 841 – 876 nm,

0.5 nm CW Shift, Gain 1% ,Offset 0.01 Wm⁻²sr⁻¹band⁻¹, 1% Noise



CLARREO Nadir = 665 FOV

OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
0.0099 ± 0.0033	0.98 ± 0.12

* Offset $2\sigma \sim 0.2\%$

* Noise reduction by averaging in $0.08 \text{ Wm}^{-2}\text{sr}^{-1}\text{band}^{-1}$ bins, $N > 100$ FOV.

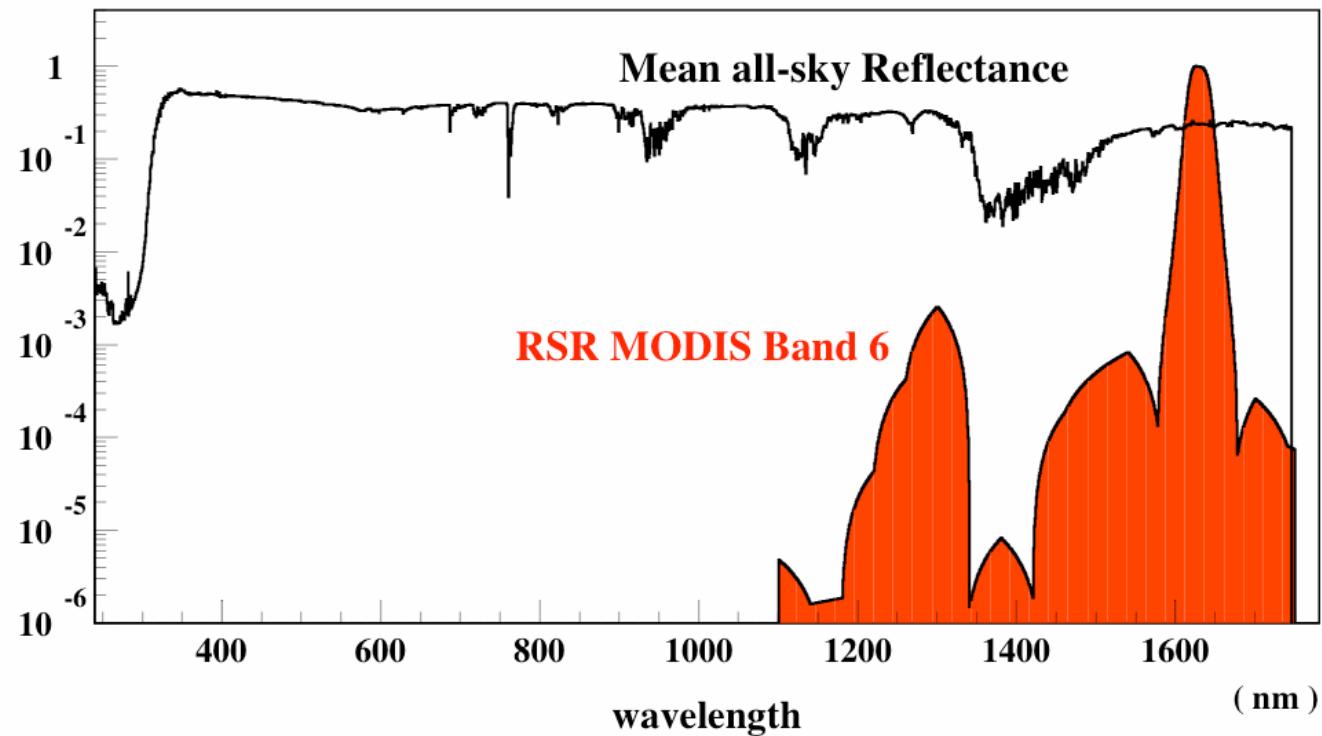
CLARREO Pointing = 25,435 FOV

OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
0.010 ± 0.001	0.92 ± 0.03

* Offset $2\sigma \sim 0.05\%$

CLARREO/MODIS Calibration

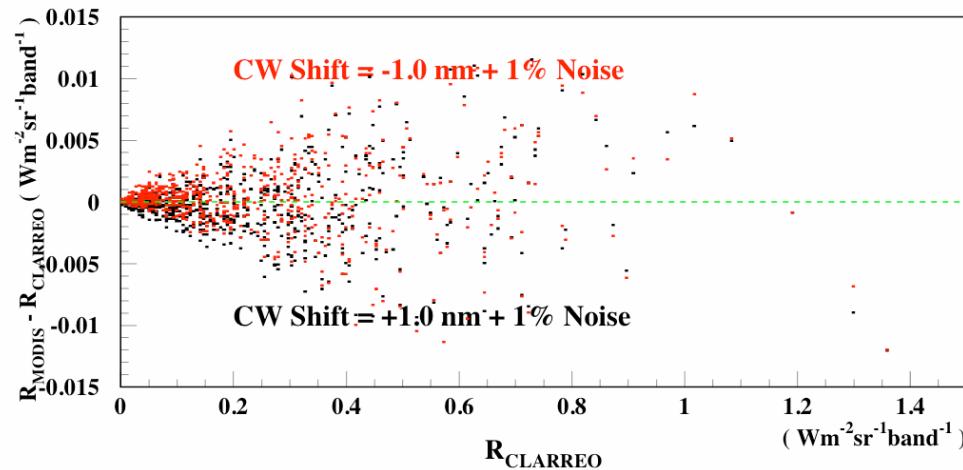
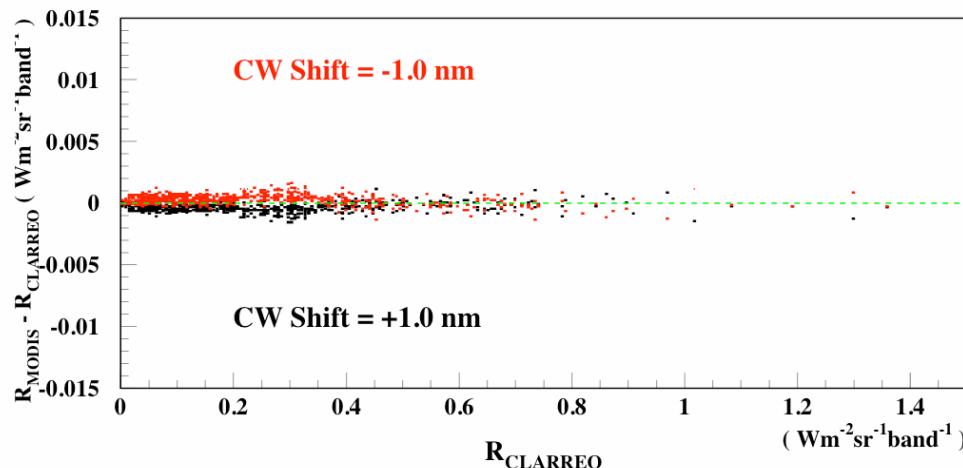
MODIS Band 6 RSR, 1628 – 1652 nm



- ◆ Reported MODIS RSR central wavelength shifts = ?

CLARREO/MODIS Calibration

**MODIS Band 6: 1628 – 1652 nm,
1.0 nm CW Shifts, Nadir-only Sampling, 1% Matching Noise**



CW SHIFT ONLY :

Shift (nm)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
+1.0	-3.6e-04 ± 0.4e-04	0.011 ± 0.013
-1.0	4.1e-04 ± 0.5e-04	-0.048 ± 0.015

CW SHIFT + NOISE = 1% :

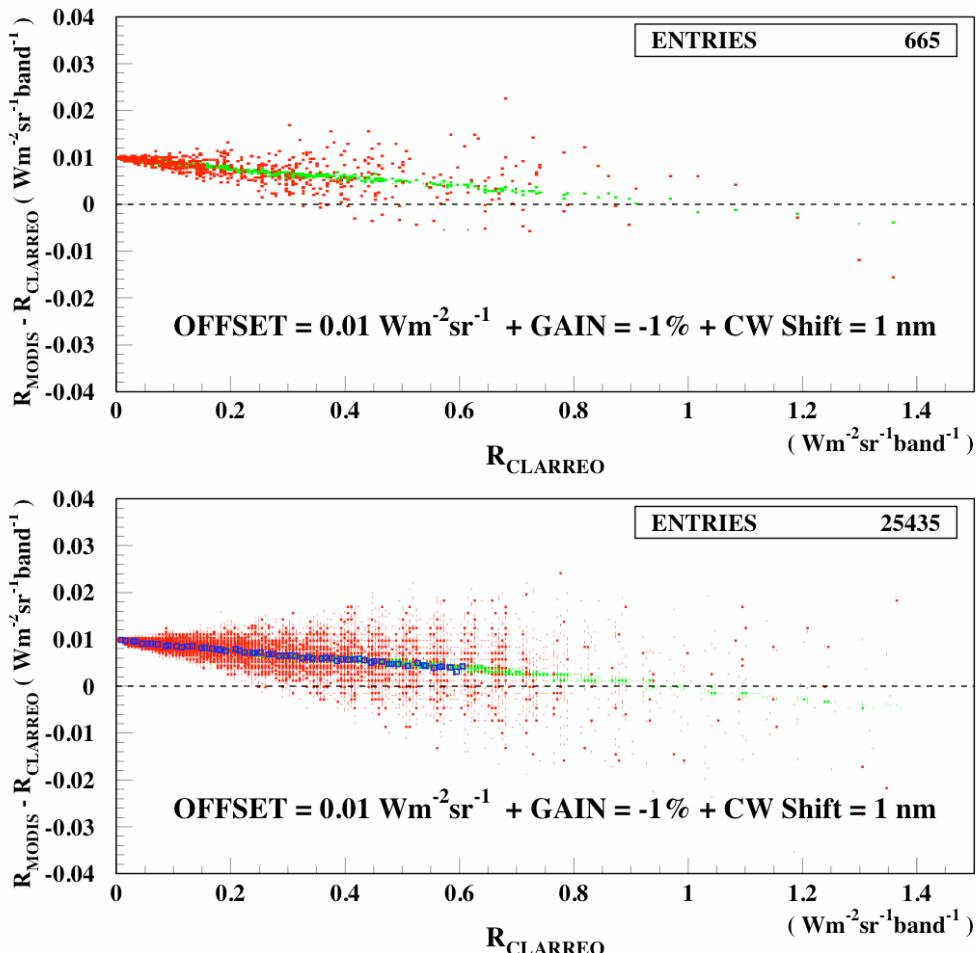
Shift (nm)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
+1.0	-4.8e-04 ± 3.4e-04	0.11 ± 0.11
-1.0	2.9e-04 ± 3.4e-04	0.05 ± 0.11

* Format: PAR ± 95%CL (2σ)

CLARREO/MODIS Calibration

MODIS Band 6: 1628 – 1652 nm,

1 nm CW Shift, Gain -1% ,Offset 0.01 Wm⁻²sr⁻¹band⁻¹, 1% Noise



CLARREO Nadir = 665 FOV

OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
0.0095 ± 0.0003	-0.89 ± 0.11

* Offset $2\sigma \sim 0.2\%$

* Noise reduction by averaging in $0.01 \text{ Wm}^{-2}\text{sr}^{-1}\text{band}^{-1}$ bins, $N > 100$ FOV.

CLARREO Pointing = 25,435 FOV

OFFSET ($\text{Wm}^{-2}\text{sr}^{-1}$)	GAIN (%)
0.0096 ± 0.00012	-0.990 ± 0.035

* Offset $2\sigma \sim 0.08\%$

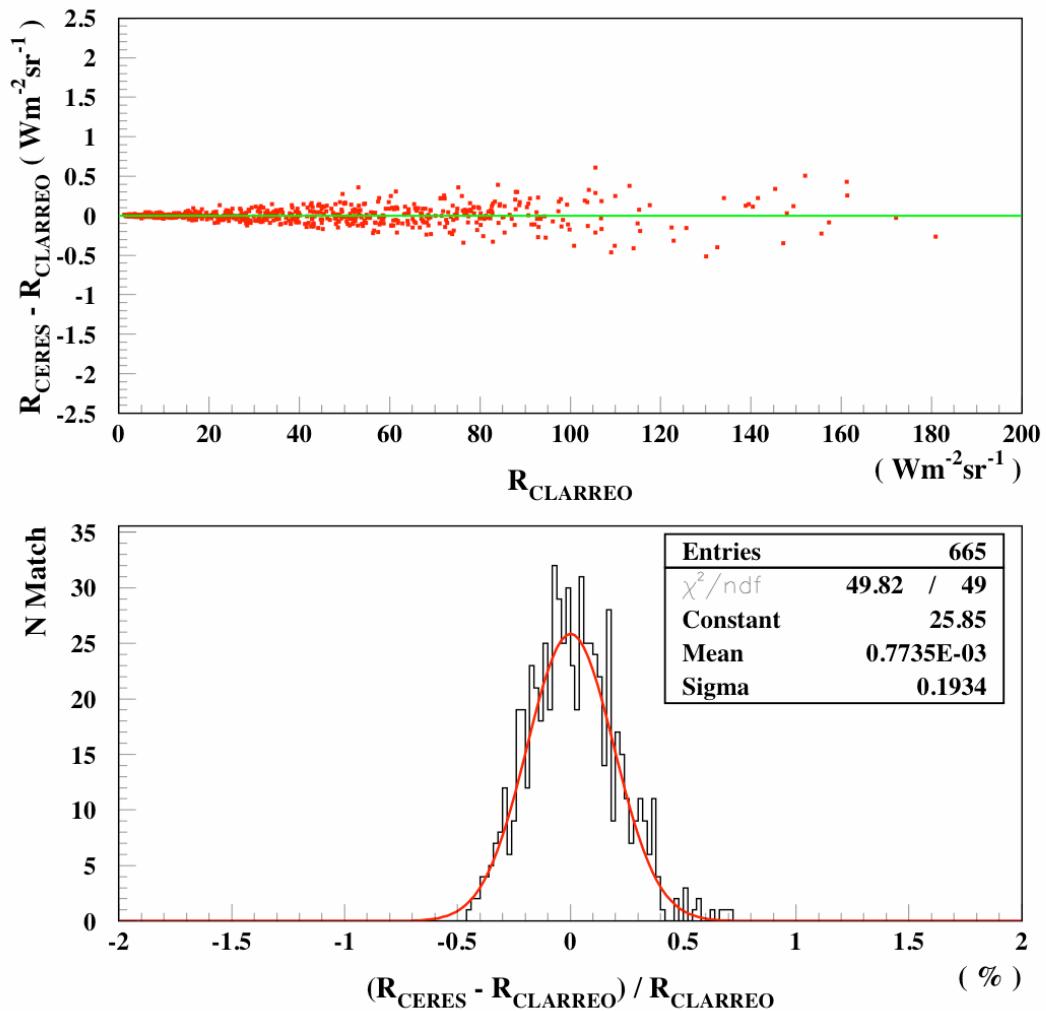
Summary for CLARREO / MODIS Inter-Calibration

- ◆ For selected bands inter-calibration uncertainty is dominated by contribution from matching noise.
- ◆ Effects from RSR central wave shifts below 1 nm are very small for MODIS bands 1, 2 and 6.
- ◆ Simulation is not sensitive to spectral shifts below the resolution → CLARREO resolution ?
Possible simulation at 0.25 nm, 1.0 nm, 2.0 nm ?
- ◆ CLARREO basic scene ID is needed for studying non-linear effects due to RSR degradation.
- ◆ Depending on band, large sampling reduces uncertainty from offset/gain factor 2-3.

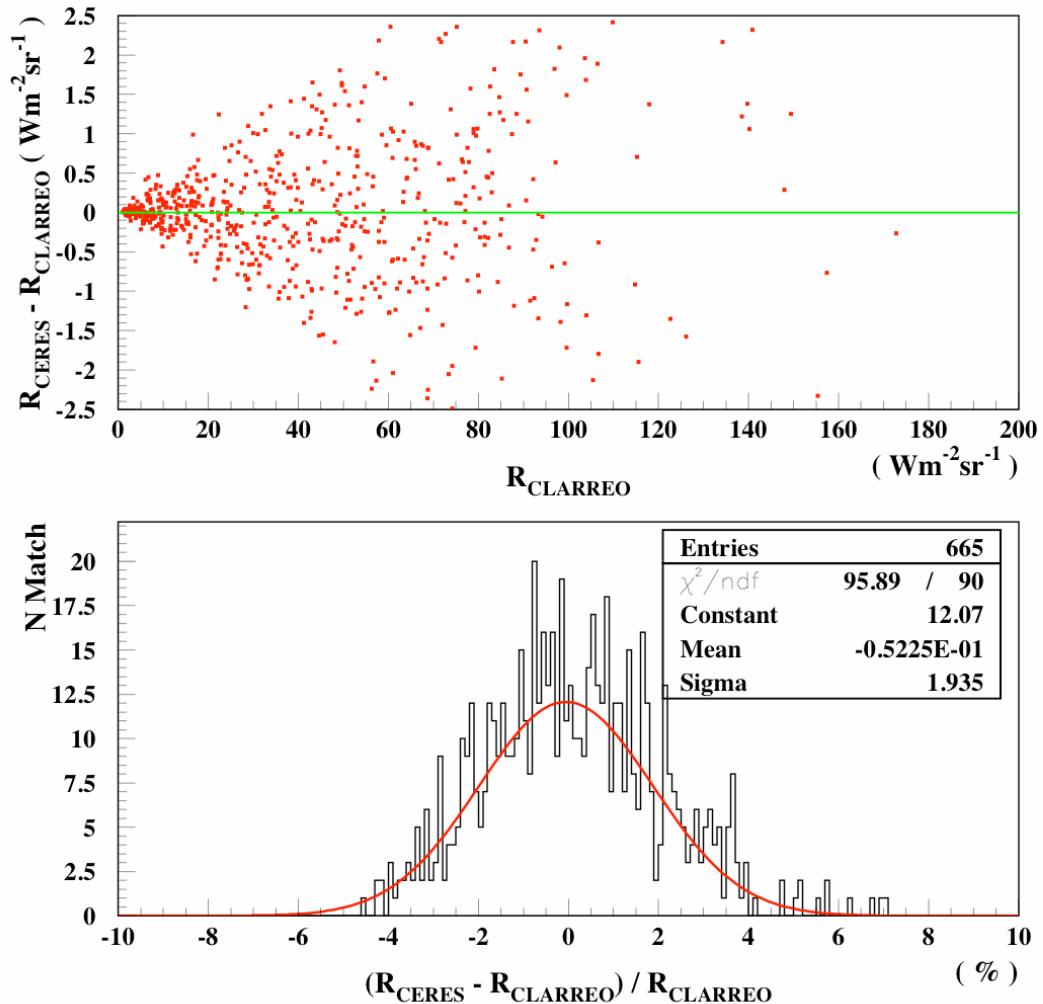
Future Work

- ◆ **Include SCIAMACHY data for April and October months into simulation (by Spring 2009).**
- ◆ **Develop basic CLARREO-only scene ID for clear-sky ocean, clear-sky desert, DCC and marine stratus clouds (by Winter 2008 - 2009).**
- ◆ **Simulation of CLARREO matching sampling with different orbits (by Winter 2008 - 2009).**
- ◆ **CLARREO sampling as ensemble of scene types modeled after CERES/MODIS (by Spring 2009).**
- ◆ **Perform simulation for other instruments and MODIS bands (by Spring 2009).**
- ◆ **Include more cases of RSR degradation, CW shifts, matching noise (0.5%, 2%) (Spring 2009).**

Matching Noise: Random Gaussian $\sigma = 0.2\%$

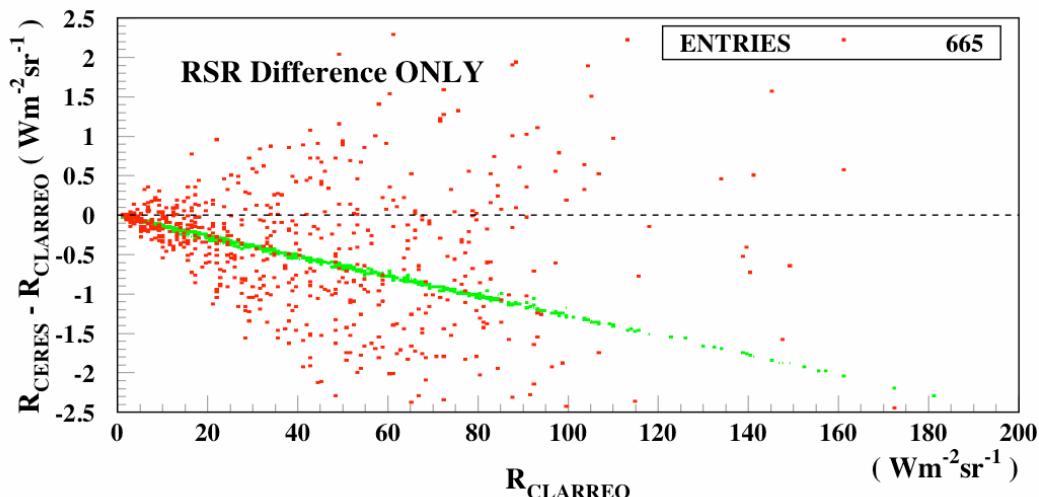
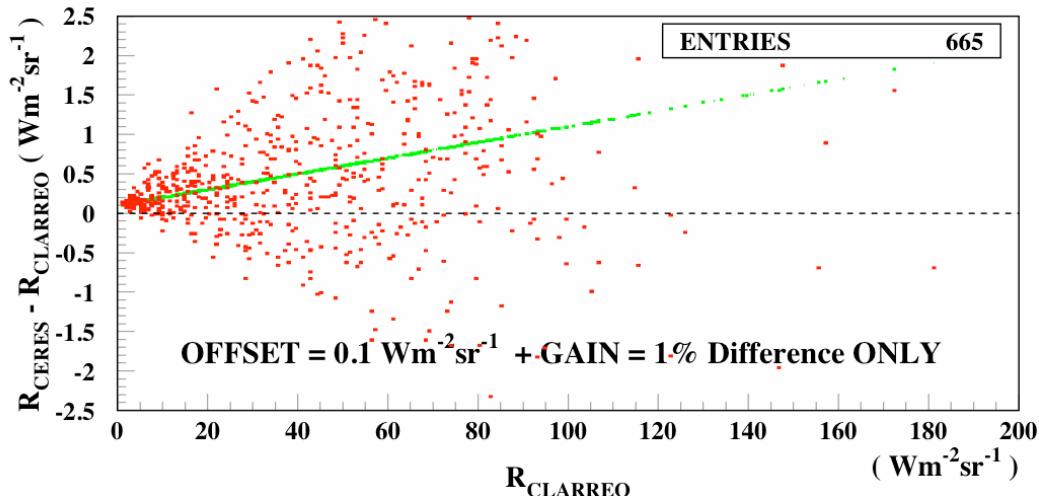


Matching Noise: Random Gaussian $\sigma = 2\%$



CLARREO/CERES Calibration

Offset = 0.1 Wm⁻²sr⁻¹, Gain = 1%, Noise σ = 2%



OFFSET + GAIN ONLY :

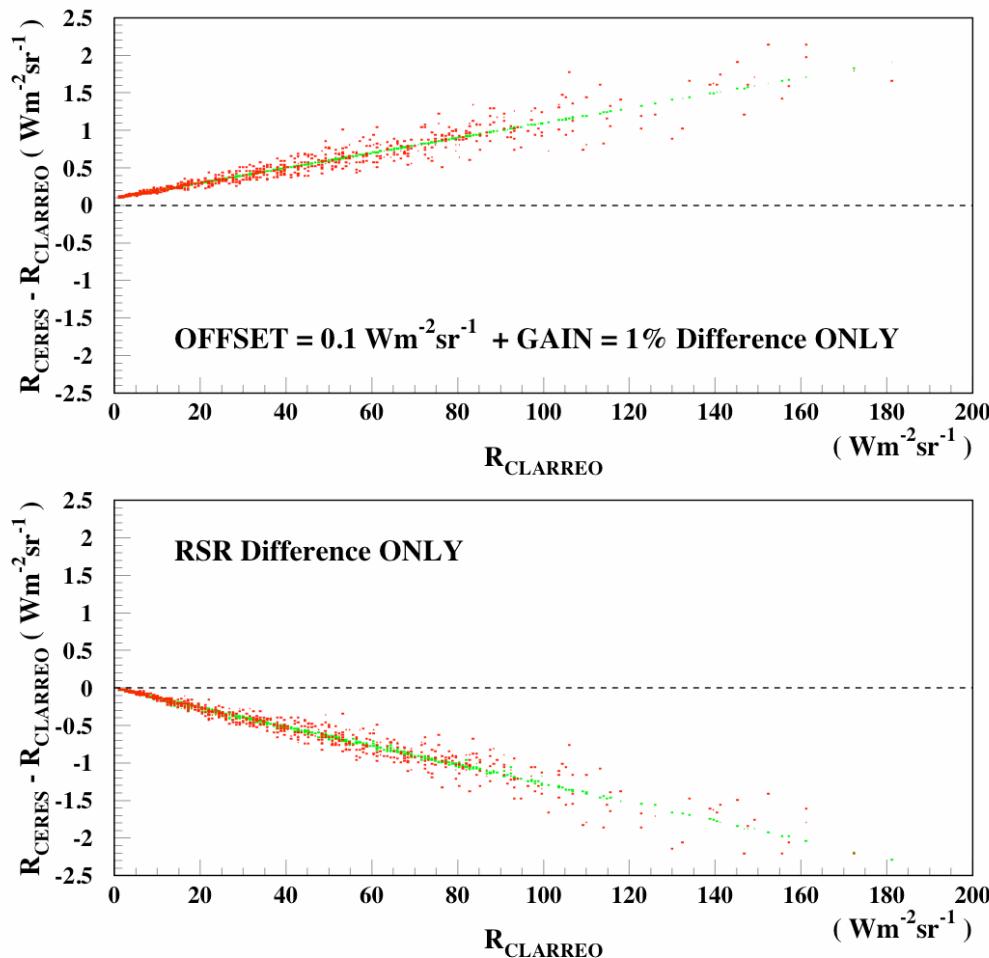
Noise	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
2%	0.08 ± 0.14	1.13 ± 0.25

RSR ONLY :

Noise	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
2%	-0.03 ± 0.14	-1.14 ± 0.25

CLARREO/CERES Calibration

Offset = 0.1 Wm⁻²sr⁻¹, Gain = 1%, Noise σ = 0.2%



OFFSET + GAIN ONLY :

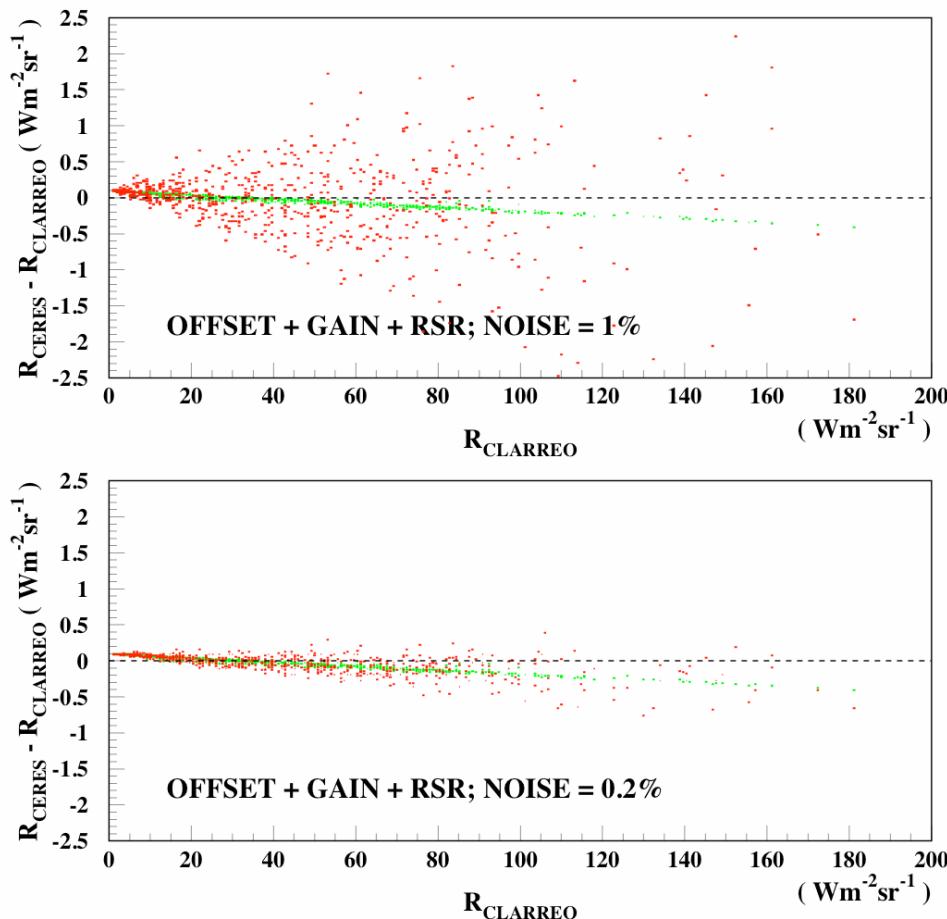
Noise	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
0.2%	0.098 ± 0.014	1.01 ± 0.025

RSR ONLY :

Noise	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
0.2%	-0.018 ± 0.014	-1.25 ± 0.025

CLARREO/CERES Calibration

Offset = 0.1 Wm⁻²sr⁻¹, Gain = 1%, RSR



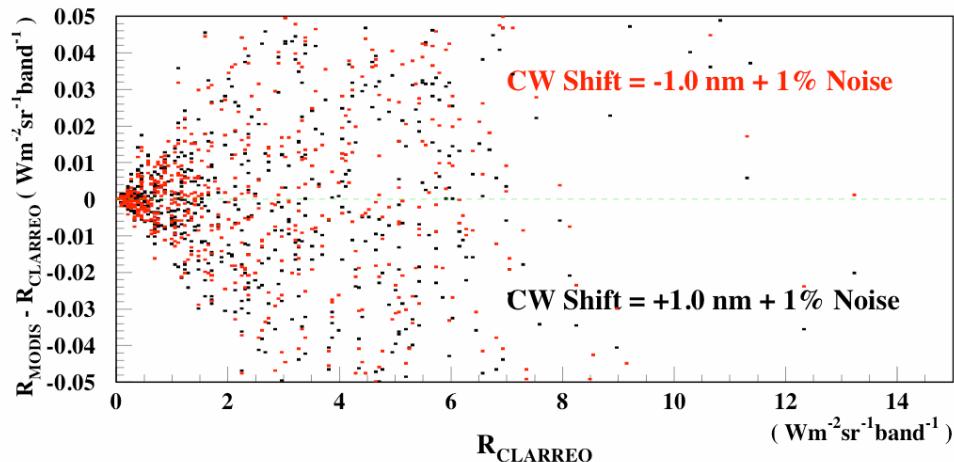
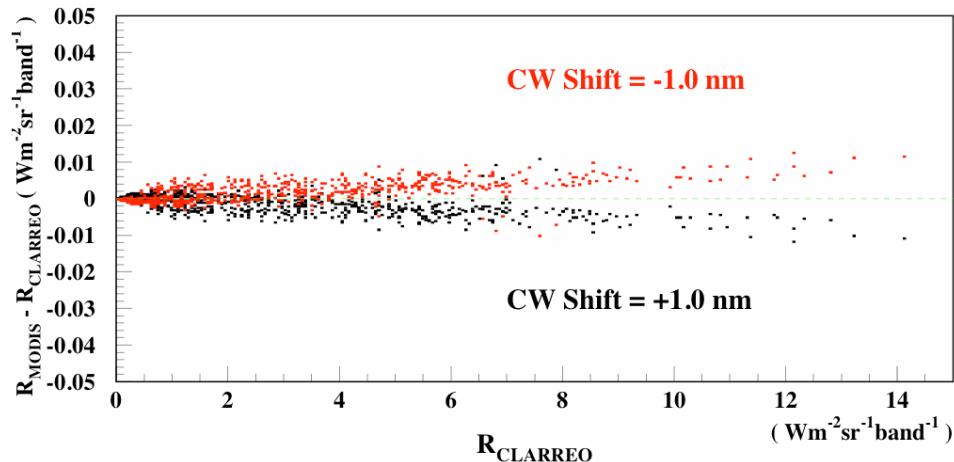
OFFSET + GAIN + RSR :

Noise (%)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
0.0	0.080 ± 0.003	-0.270 ± 0.005
0.2	0.082 ± 0.014	0.260 ± 0.025
1.0	0.075 ± 0.070	-0.21 ± 0.13

CLARREO/MODIS Calibration

MODIS Band 1: 620 – 670 nm,

1 nm CW Shifts, Nadir-only Sampling, 1% Matching Noise



CW SHIFT ONLY :

Shift (nm)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
+1.0	1.5e-04 ± 2.6e-04	-0.058 ± 0.006
-1.0	-1.4e-04 ± 2.6e-04	0.065 ± 0.006

CW SHIFT + NOISE = 1% :

Shift (nm)	OFFSET (Wm ⁻² sr ⁻¹)	GAIN (%)
+1.0	-1.2e-04 ± 5.0e-03	-4.6e-04 ± 0.12
-1.0	-4.2e-04 ± 5.1e-03	0.12 ± 0.12